Semantic Parsing and its Applications in Code Generation

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Problem Overview

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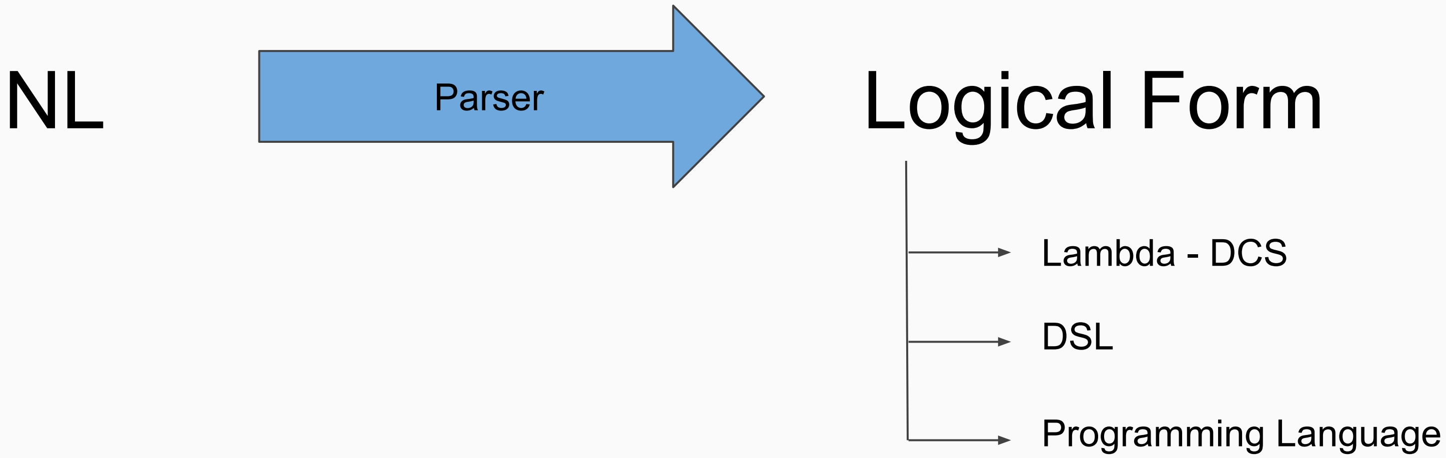


Problem Overview: Natural Language Interfaces

What are the ids of stations that are located in San Francisco and have average bike availability above 10?

Interface

```
(SELECT id
FROM station
WHERE city  =  "San Francisco")
INTERSECT
(SELECT station_id
FROM status
GROUP BY station_id
HAVING avg( bikes_available )  >  10)
```

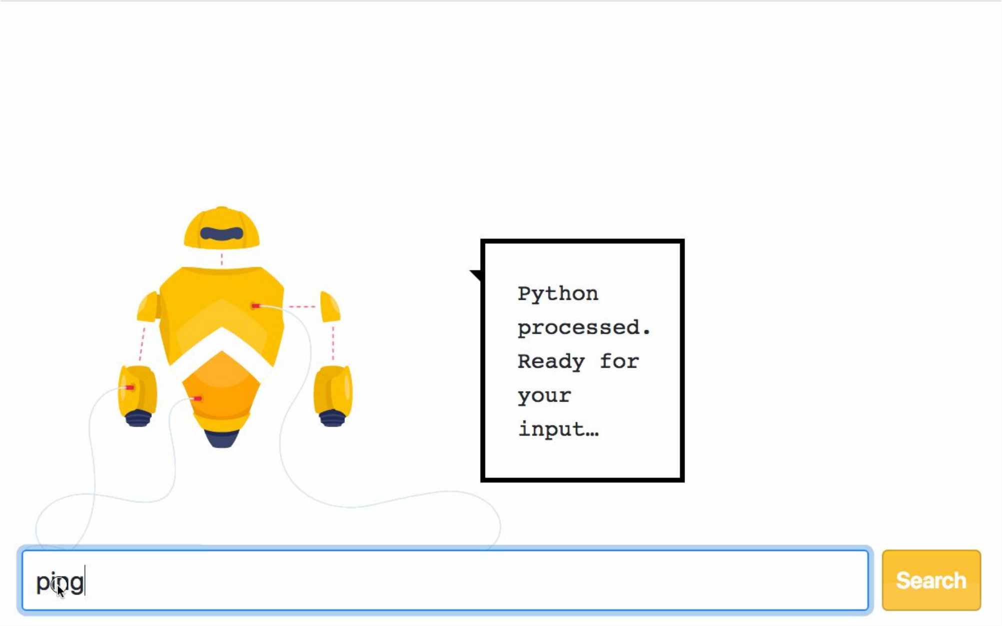
Query

S.No.	ID No.
1	13225
….. ….	…… …..
n	37724

Return Result

Problem Overview: Semantic Code Search/Generation

- Programmer-oriented use-case
- Search for code by functionality
- Generate code via NL



Source: https://githubengineering.com/towards-natural-language-semantic-code-search/

Problem Overview: Robot Navigation

- Communicating with robots using NL
- Conversion of instruction to DSL
- Context-dependent instructions

Previous instruction:

Go to the tree on the right

Previous interpretation:

$\lambda a.\mathtt{move}(a) \wedge \lambda x.\mathtt{tree}(x) \wedge \mathtt{right\text{-}of}(x, \mathtt{rock}) \wedge \mathtt{to}(a, x)$

Current instruction:

Go to the other tree

$\lambda a.\mathtt{move}(a) \wedge \lambda x.\mathtt{tree}(x) \wedge \neg\mathtt{right\text{-}of}(x, \mathtt{rock}) \wedge \mathtt{to}(a, x)$

Source: https://github.com/allenai/acl2018-semantic-parsing-tutorial/blob/master/slides/context_dependent_parsing.pdf

Traditional vs Neural Parsing

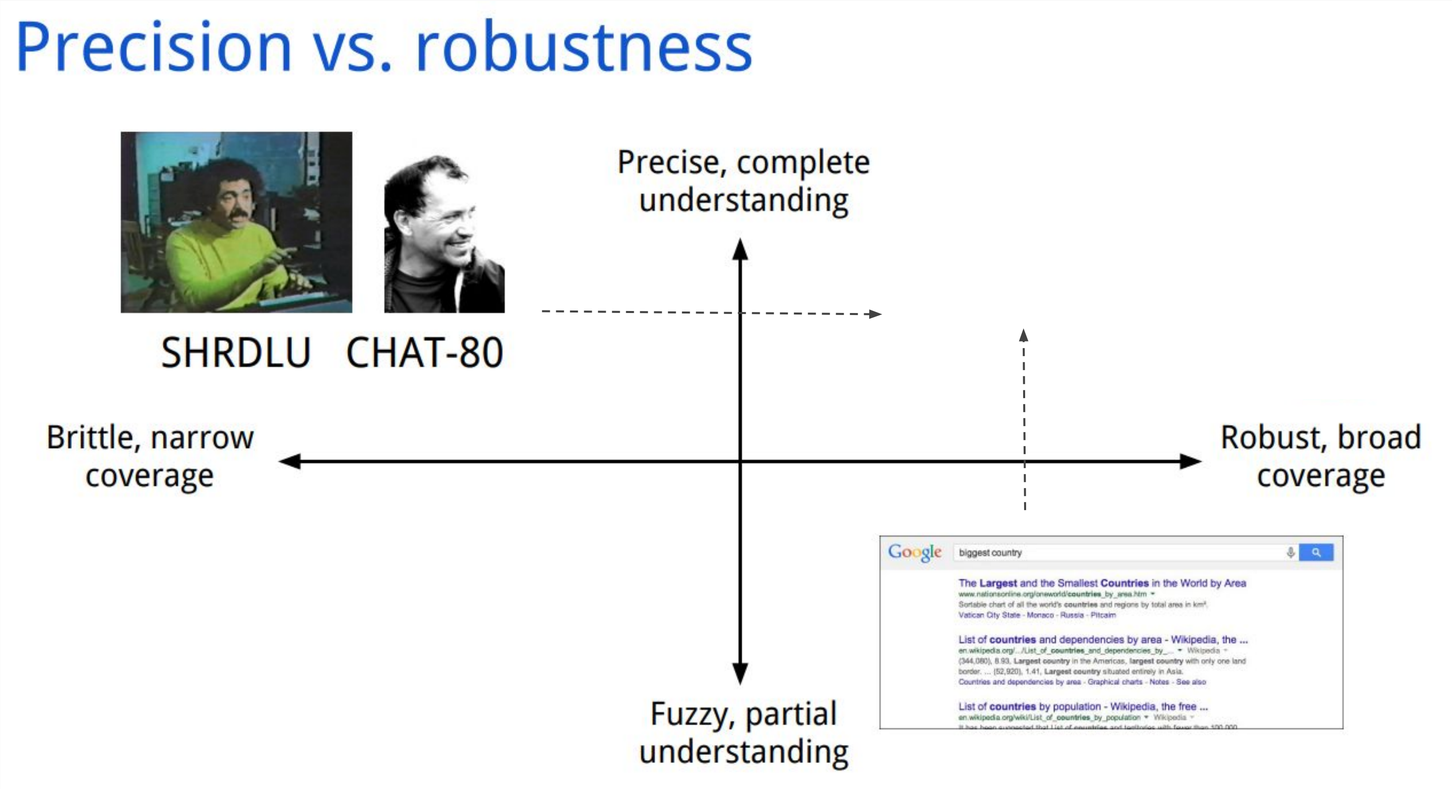
Traditional

- Manual grammar+lexicon creation
- Deterministic or probabilistic parsing
- Highly accurate parsing
- Restricted domain

Neural

- Parsing as sequence-to-sequence generation problem
- Data-driven
- Robust, scalable
- Margin of error

Why is it difficult?



Source: https://web.stanford.edu/class/cs224u/materials/cs224u-2016-intro-semparse.pdf

Objectives and Progress

Model Objectives

- NL2Regex
- Study, implement different parsing techniques
- Beat the state-of-the-art model

Data Objectives

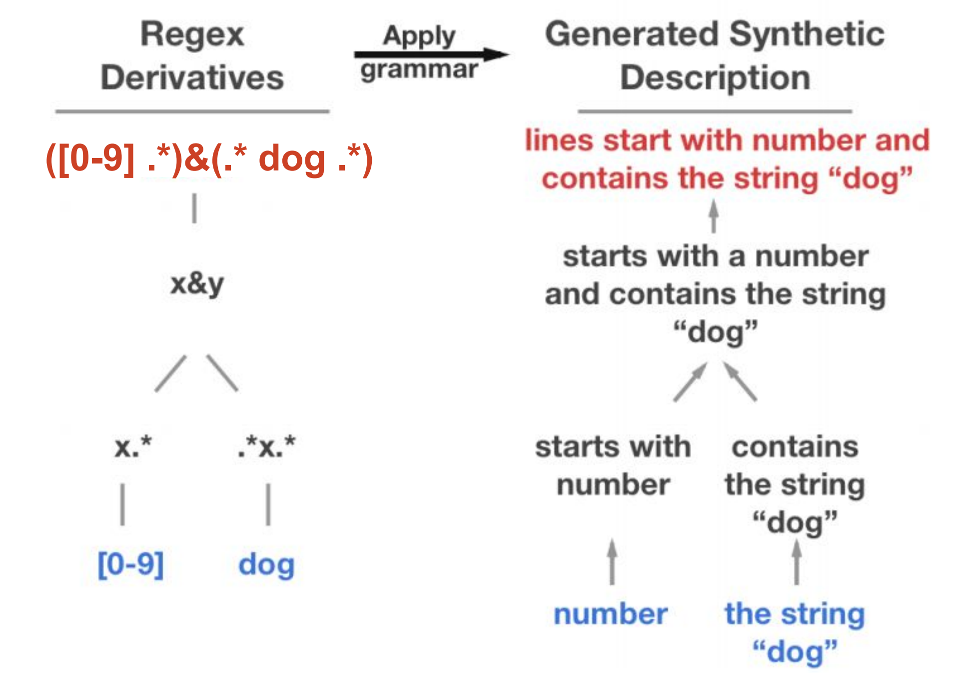
- Study existing datasets
- Identify failure points in datasets
- Analyze efficiency of data collection techniques

Model Objectives

NL2Regex

NL-RX dataset (Locascio et.al 2016)

- 10,000 pairs of NL descriptions and regex
- Grammar-based generation + paraphrasing



Lines start with number and contains the string “dog”

Paraphrase

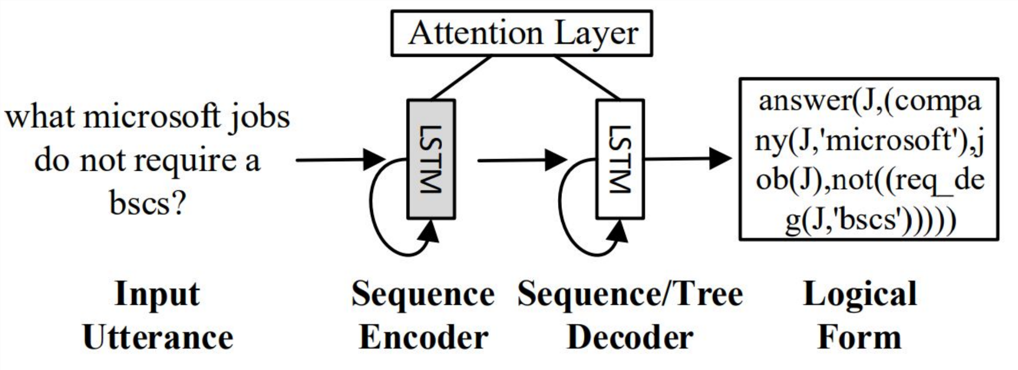
Lines which start with a number and contain the string “dog” in it.

Semantic Parsing Models: Current SOTA

- Seq2Seq w/ attention

Advantages:
- Quick to train
- Robust to variation

Disadvantages:
- No structural integrity in logical form
- Unable to handle large nesting in logical forms

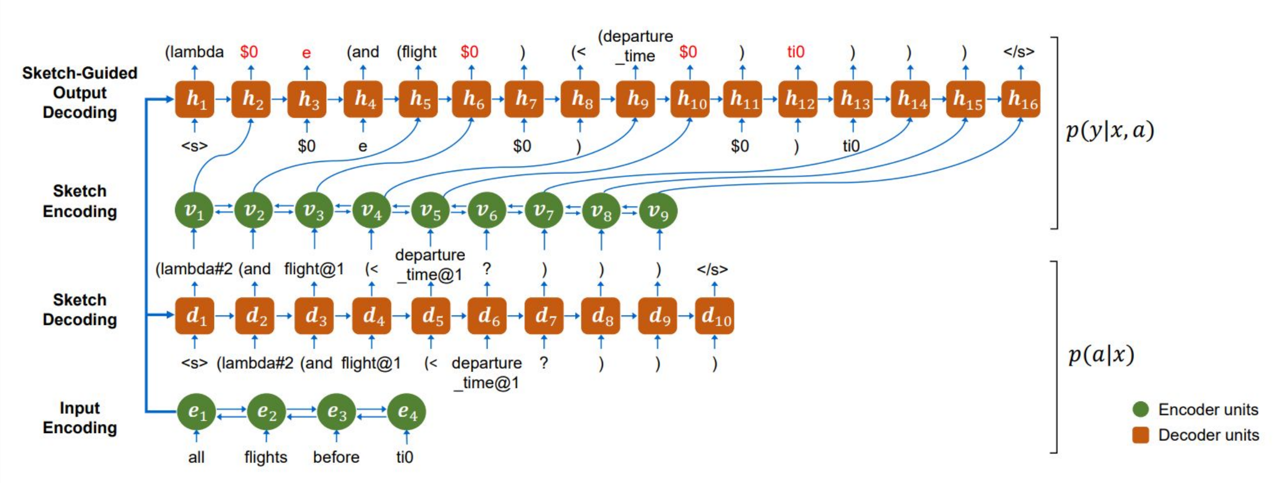


Source: [Language to Logical Form with Neural Attention (Dong and Lapata 2016)]

Semantic Parsing Models: Coarse2Fine

Two stages of encoding-decoding:

1. NL is encoded, sketch is decoded
2. Sketch is encoded, logical form is decoded



Advantages:

- Structure is encoded, guides decoding throughout
- Work of encoding-decoding is divided

Disadvantages:

- May still result in syntax errors

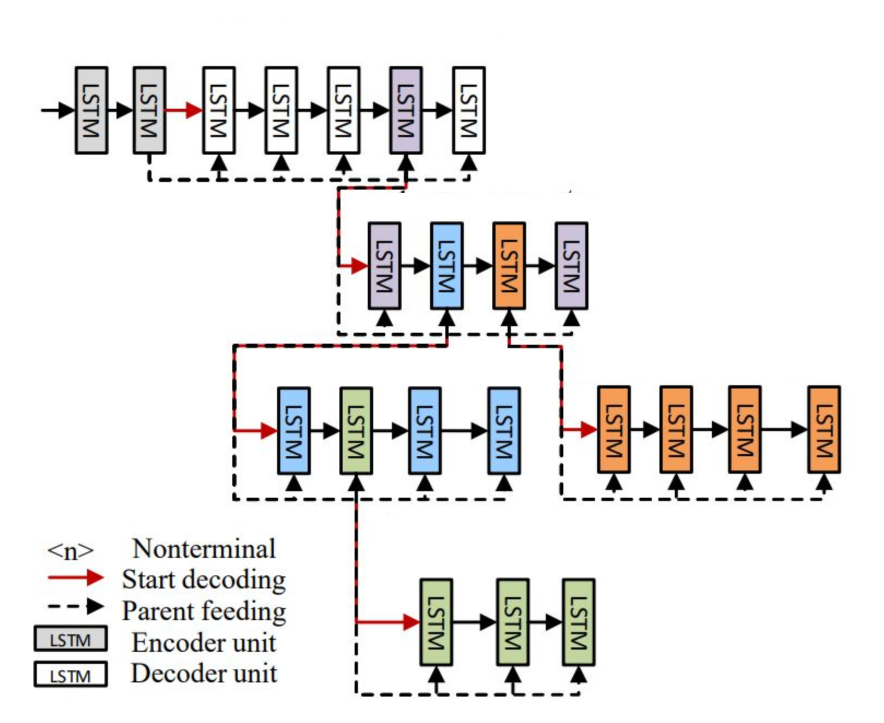
Source: [Coarse-to-Fine Decoding for Neural Semantic Parsing](#) [(Dong and Lapata 2018)](#)

Semantic Parsing Models: Seq2Tree

- Tree decoder instead of sequence decoder

Advantages:
- Leverages tree/nested nature of code during decoding

Disadvantages:
- Structure is not encoded explicitly, does not guide the decoding



Source: [Language to Logical Form with Neural Attention (Dong and Lapata 2016)]

Semantic Parsing Models: Abstract Syntax Networks

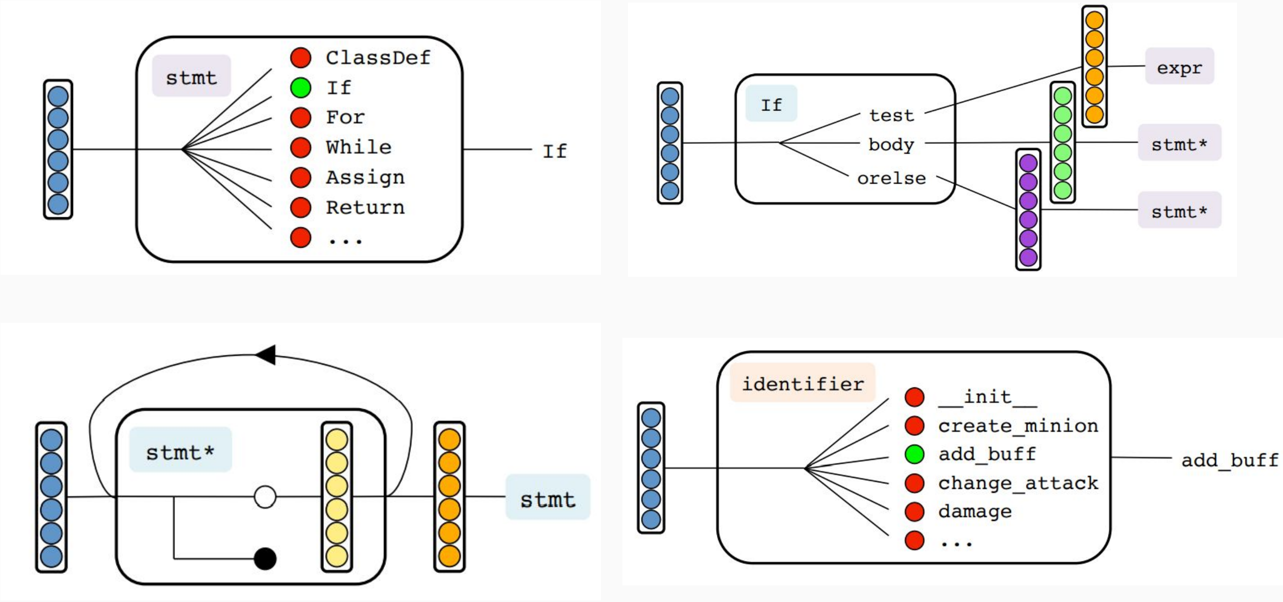
- Recursive calls of decoding modules

Advantages:

- Leverages recursive nature of general programs
- Output is always syntactically correct

Disadvantages:

- Lack of effective encoding of NL
- Not generalizable to all semantic parsing problems



Source: [Abstract Syntax Networks for Code Generation and Semantic Parsing (Rabinovich et.al. 2017)]

Semantic Parsing Models: Multi-Task Learning Models

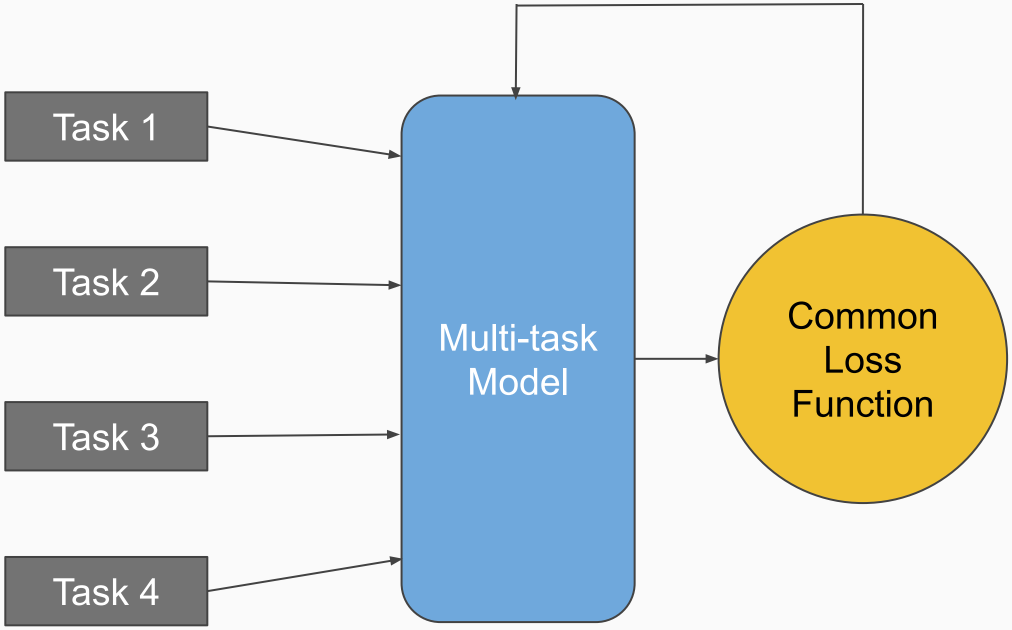
- Joint training of multiple tasks
- Common loss function

Advantages:

- Learns more informed representation of NL
- Encoding of NL is more advanced

Disadvantages:

- No structural integrity of decoding



Results on NL2Regex Dataset

Model	**Exact Matching Accuracy**	**DFA-Equals Accuracy**
Baseline (Seq2Seq + Copy)	38.96%	55.24%
Current SOTA	38.6%	58.2%
Coarse2Fine	42.52%	59.68%
Multi-task Network (MQAN)	**44.96%**	**61.92%**

Error Analysis

1. Incorrect Paraphrasing

Synth: lines having either a lower-case letter , the string "dog" , or a number before a capital letter
Paraphrase: lines containing a lower - case letter and the word dog , followed by a number , then a capital letter

Correct regex: (([a-z]) | (dog) | ([0-9])) .* ([A-Z]) .*
Predicted regex: (([a-z]) & (dog)) .* ([0-9] .* [A-Z] .*) .*

2. Transferred ambiguity

Synth: lines with the string "dog" before the string "truck" or the string "ring" , 6 or more times
Paraphrase: lines with string "dog" before string "truck" or string "ring" , 6 or more times

Correct regex: (((dog) .* (truck) .*) | (ring)) {6,}
Predicted regex: ((dog) .* (truck) .*) | ((ring) {6,})

3. Large syntactic variation

Synth: lines containing a character and a lower-case letter
Paraphrase: a character and a lower cased letter is required of lines

Correct regex: .* (.) & ([a-z]) .*
Predicted regex: ((.) & ([a-z])) .* ([0-9]) .*

Data Objectives

Existing Datasets: NL2Program Datasets

1. Hearthstone


```python
class DireWolfAlpha(MinionCard):
  def __init__(self):
    super().__init__(
      "Dire Wolf Alpha", 2, CHARACTER_CLASS.ALL,
      CARD_RARITY.COMMON, minion_type=MINION_TYPE.BEAST)
  def create_minion(self, player):
    return Minion(2, 2, auras=[
      Aura(ChangeAttack(1), MinionSelector(Adjacent()))
    ])
```

2. NL2Bash

display the 5 largest files in the current directory and its sub-directories

```bash
find . -type f | sort -nk 5,5 | tail -5
du -a . | sort -rh | head -n5
```

3. Django

join app_config.path and string 'locale' into a file path, substitute it for localedir.

```python
localedir = os.path.join(
    app_config.path, 'locale')
```

4. CoNaLa

How can I send a signal from a python program?

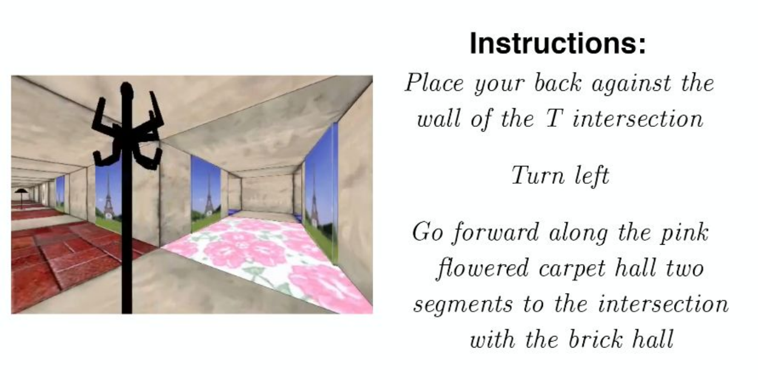
```python
os.kill(os.getpid(), signal.SIGUSR1)
```

Existing Datasets: NL2DB datasets

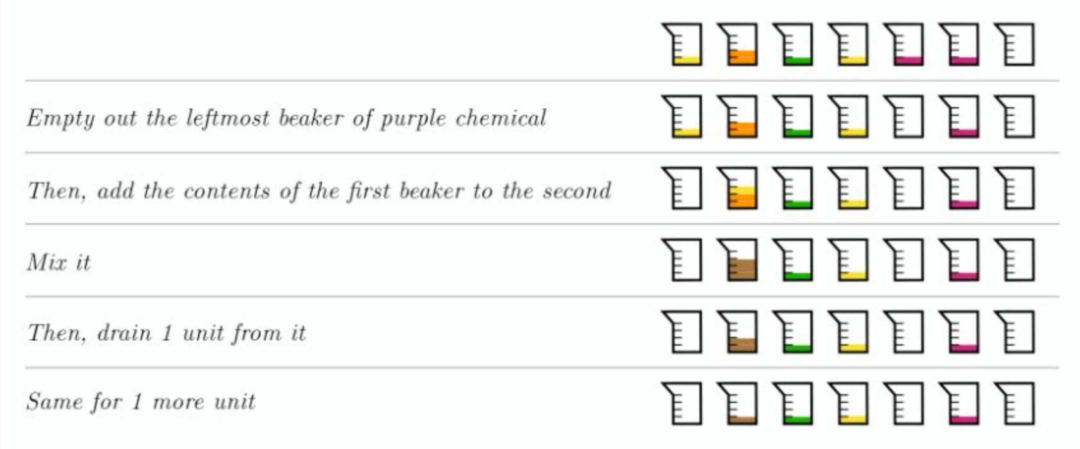
Name	**Domain**	**NL**
ATIS	Airline Booking	What flights from any city land at airport_code0 ?
GeoQuery	US Geography	could you tell me what is the highest point in the state of Utah ?
WikiSQL	Various (e.g. Movies, Sports, History)	Srdjan Dragojevic worked on a film which earned what nomination?
Spider	Various (e.g. Games, Class schedules, U.S. government)	For every student who is registered for some course, how many courses are they registered for?

Existing Datasets: Sequential, Context-Dependent Datasets

Navi



SCONE



Factors to determine data quality

Natural Language

- **NL Variation**
  - Lexical
  - Phrasal
  - Syntactic
- **NL Quality**: Grammatical errors, mispellings,etc.
- **Level of Anaphora**
- **Domain span**

Logical Forms

- **LF Variation**: Coverage
- **LF Complexity**: Nesting (depth)
- **LF Consistency**: Dense distribution of LFs
- **LF Quality**: Syntactic and semantic accuracy

Some Qualitative Observations

Dataset	NL variation	NL Quality	Level of Anaphora	LF variation	LF complexity	LF consistency	LF Quality	Domain Span
NL2Regex	❌	❌	❌	❌	❌	✔	❌	❌
Django	❌	✔	❌	✔	✔	✔	✔	✔
WikiSQL	✔	✔	❌	❌	❌	✔	✔	✔
Spider	✔	✔	❌	✔	✔	✔	✔	✔
Scone	❌	✔	✔	✔	✔	✔	✔	❌

Quantitative Analysis Metrics

Natural Language

1. Size of vocabulary
2. Av. length of datapoint
3. Level of anaphora
4. N-gram variation
5. Zipf distribution of words

Logical Forms

1. Av. number of nodes in AST (Gen. purpose programs only)
2. Av. number of operators/operands
3. "N-gram variation"

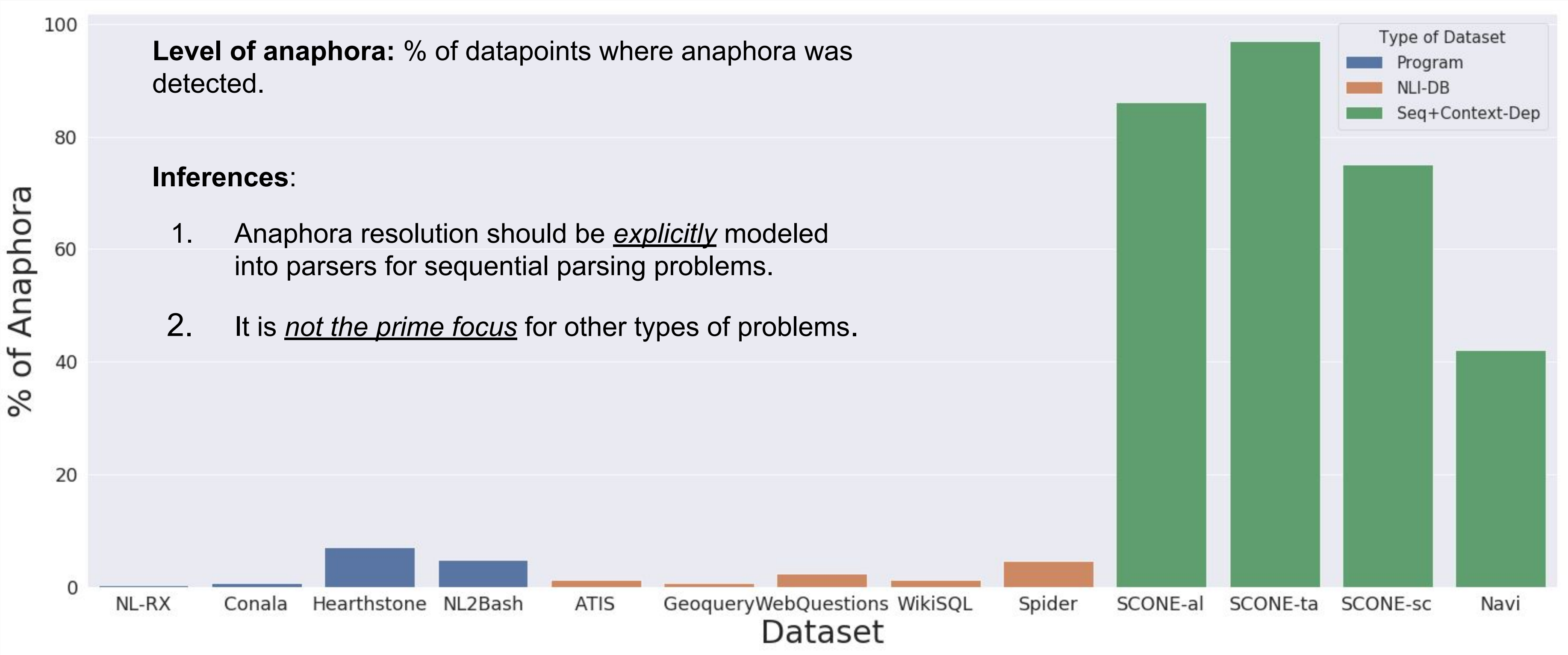
Some Quantitative Results: Level of Anaphora

Level of anaphora: % of datapoints where anaphora was detected.

Inferences:

1. Anaphora resolution should be *__explicitly__* modeled into parsers for sequential parsing problems.

2. It is *__not the prime focus__* for other types of problems.



Some Quantitative Results: Zipf distribution of words

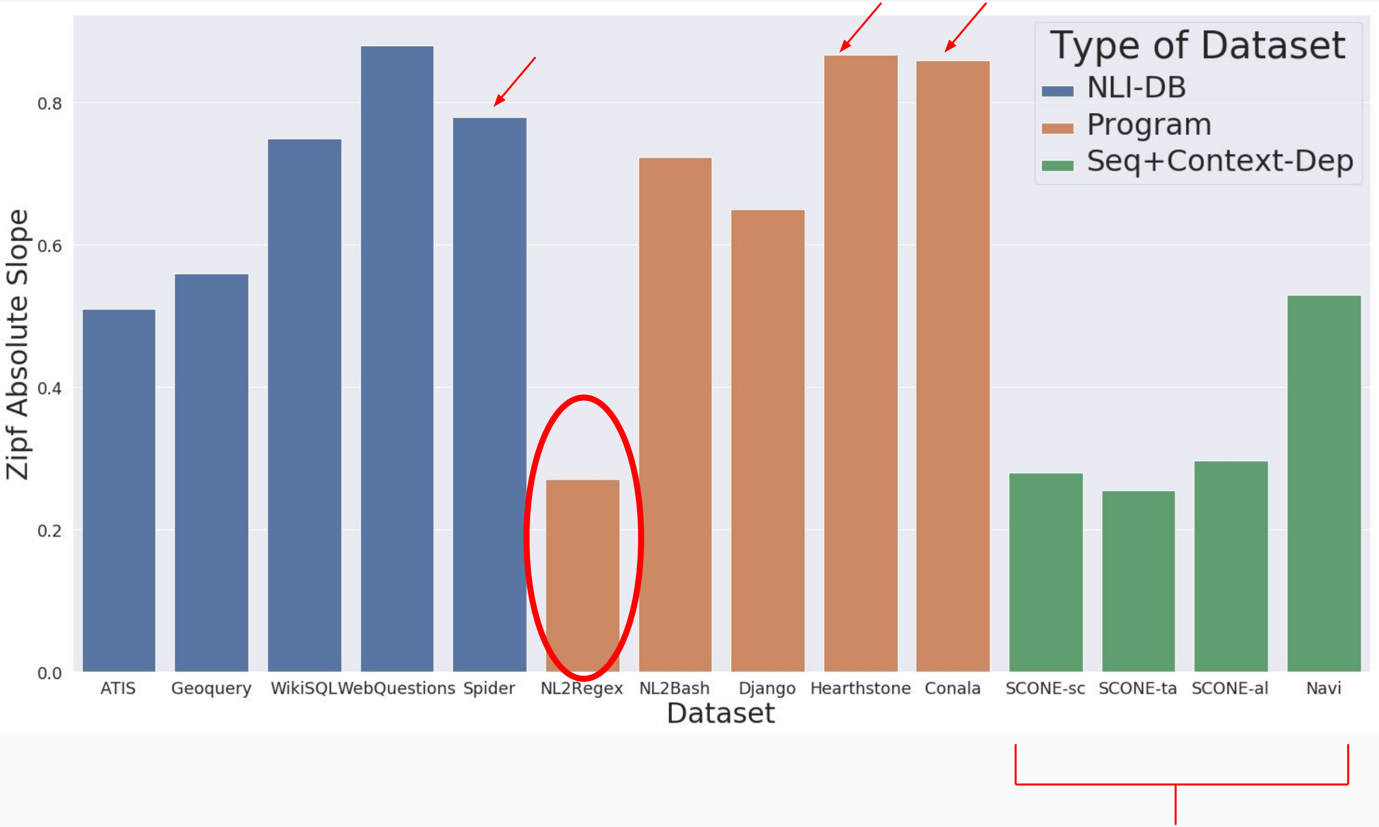
Zipf Absolute Slope:

Slope of plot of log(freq. of word) vs. log(rank of word)

The **closer to 1**, the better the frequency distribution of words

Inferences:

1. Good datasets have *high* Zipf slope (Spider, Conala, Hearthstone)
2. NL2Regex has *poor distribution*
3. Seq+Context-dep datasets *don't focus* on accurate distribution



Data Cleaning

- How to *abstract away* the task and logical form complexity from NL variation?

- Three step cleaning:
  - Replace named entities with **<NE>**
  - Replace words which are *not common words* and have *frequency > 3* with **<KW>**
  - Replace those with *frequency < 3* with **<NE>**

Django NL query:

call the function _create_cache with argument alias

NL2Regex NL query:

lines with the string 'dog' at least 2 times

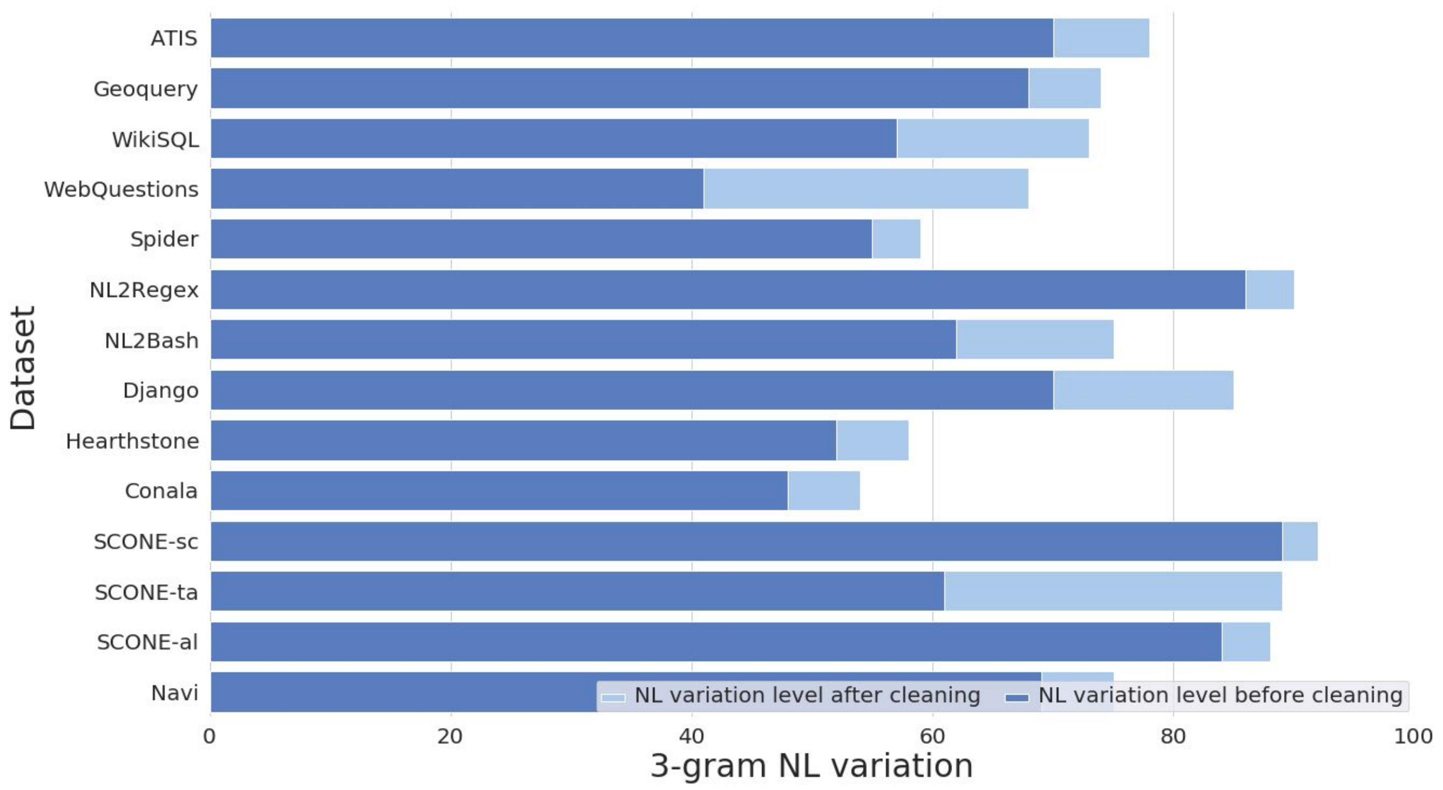
Some Quantitative Results: N-gram NL variation

3-gram NL variation:

1. Sort unique 3-grams in descending order of frequency
2. Take top 20% of this list, and find % of datapoints which contain these 3-grams
3. The *higher the %*, the *less variation* there is.

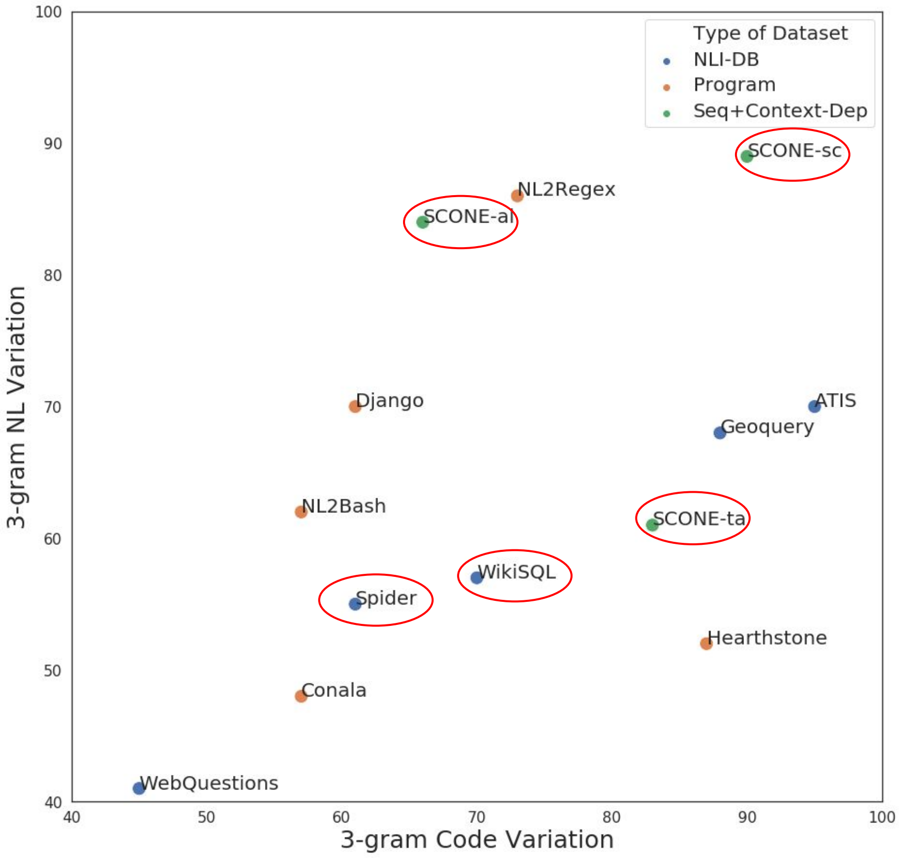
Inferences:

1. Django dataset and NL2Regex datasets *comparable*.
2. Spider *maintains* variation level, whereas variation of WikiSQL is *lesser than expected*

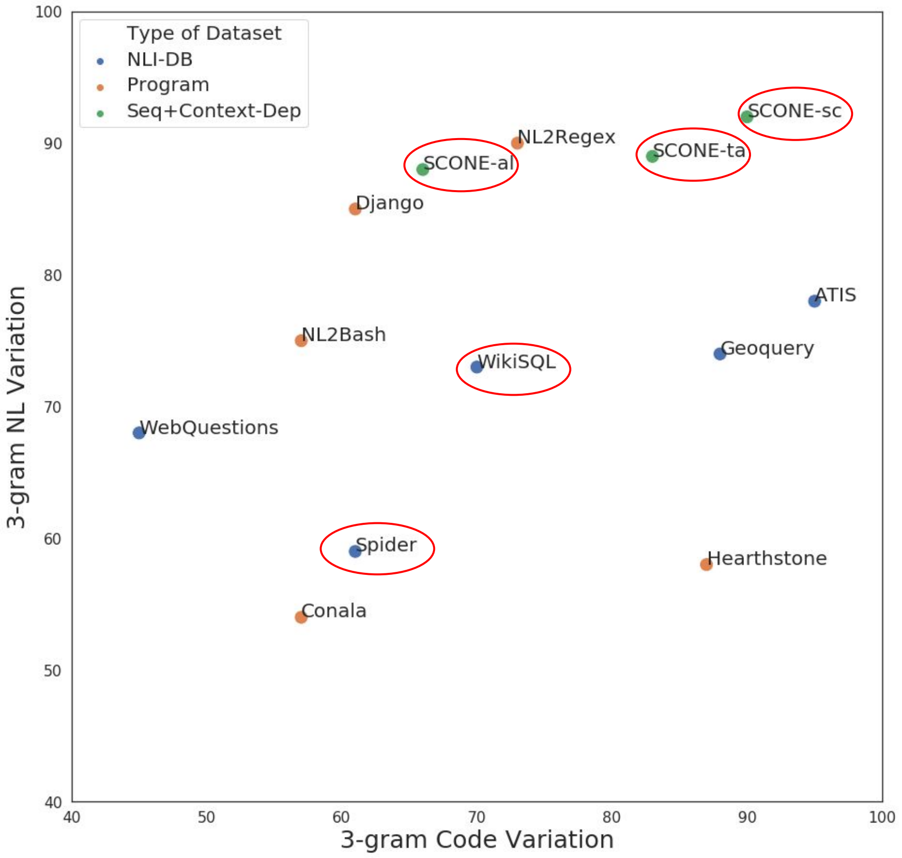


Some Quantitative Results: 3-gram NL variation vs. 3-gram Code Variation

Without cleaning



With cleaning



Data Collection Analysis

- Devised a generalized set of methods used for data collection.

LF-phase collection

Inputs:-

1. Web/Internet
2. Grammar/Lexicon
3. World State

Process:-

1. Scrape
2. Generative Model
3. Manual

LF

NL-phase Collection

Inputs:-

1. NL description
2. LF description
3. World description

Process:-

1. Generate
2. Extract
3. Paraphrase

NL

Data Collection Analysis

LF-phase Classification

		Process		
		Scrape	**Generative Model**	**Manual**
Input	**Web/Internet**	CodeNN,Conala,Geoquery, Hearthstone,IFTTT,NL2Bash	WebQuestions	
	Grammar+Lexicon	**Invalid**	NL2Regex,Overnight, WikiSQL	
	World State	**Invalid**	SCONE	ATIS,Spider

NL-phase Classification

		Process		
		Generate	**Extract**	**Paraphrase**
Input	**NL description**	WebQuestions	CodeNN,Conala,Geoquery, Hearthstone,NL2Bash,IFTTT	NL2Regex,WikiSQL, Overnight
	LF description		Conala, NL2Bash	**Invalid**
	World description	ATIS,SCONE, Spider	**Invalid**	**Invalid**

Future Work

1. Collect small regex datasets with different methods
2. Analyze the data and determine efficient data collection methods and strategies.
3. Measure code complexity with advanced measures such as :
    a. Halstead complexity
    b. Cyclometric complexity

Thank you